PYTHIA Tutorial: ME/PS Matching

LO $(2 \to 2)$ $d\sigma \oplus$ (N)LL parton showers $\oplus$ non-perturbative physics models $\neq$ adequate physics description

- Backgrounds to top, SUSY, Higgs, *etc.* contain several hard jets
- Corrections for one additional hard jet have existed for several production mechanisms and numerous decays
- `MSTP(68)=1` option mentioned previously for resonance production
- `MSTJ(41)=1` for decays (e.g. $t \to bW^+g$)

Built-in corrections are automatic

Application of other matching schemes requires user intervention

Merging ME and PS: I

We want to use both in a consistent way

- ME gives hard/wide angle emissions
- PS gives soft/collinear emission
- Want smooth matching between the two
  - limit sensitivity to where matching occurs
- No double counting of emissions
- No under counting of emissions

Merging ME and PS: II

- There have been a number of attempts to do this
- Hard emission corrections for relatively simple cases
  - $e^+e^- \to q\bar{q}$
  - DIS
  - $\gamma^*/W/Z \to$ leptons
  - Top Decay
  - PYTHIA (Sjö, et al)+HERWIG (Seymour, et al)
  - Basic Strategy:
    1. Rewrite (simple) ME^2 in terms of shower variables
    2. Reweight first emission to get this expression
- Only hardest (or first) emission correctly described
- Leading order normalization retained

PYTHIA ME Corrections to PS

Consider 1st order expression for $e^+e^- \to q\bar{q}g$

$$\frac{1}{\sigma_0}\frac{d\sigma_{ME}}{dx_1 dx_2} = \frac{\alpha_s}{2\pi} C_F \frac{1}{(1-x_1)(1-x_2)} \{x_1^2 + x_2^2\}$$

$\cdots$ and the same order in the PYTHIA PS

$$m_{13}^2 = E_0^2(1-x_2) \qquad z = \frac{E_1}{E_1+E_3}$$

$$\frac{1}{\sigma_0}\frac{d\sigma_{PS}}{dx_1 dx_2} = \frac{\alpha_s}{2\pi} C_F \frac{1}{(1-x_1)(1-x_2)}$$
$$\left\{\frac{1-x_1}{x_3}\left(1+\left(\frac{x_1}{2-x_2}\right)^2\right) + (2 \leftrightarrow 1)\right\}$$

Correct first (or hardest) emission to ME

Difficult to Generalize as a reweighting of the PS

PS Corrections to ME

Several methods have been suggested to obtain a generalization by adding PS corrections to **ME's**

ad hoc approaches have been used for some time (using, e.g., the external event machinery inside PYTHIA)

Note: ME expressions for emissions reduce to the PS ones in the soft/collinear limit (modulo Sudakov form factors)

Matching Schemes correspond to interpolation strategies between the kinematic regimes where ME's or PS's are valid

I will outline two ways I have been using PYTHIA to obtain matched samples for $W/Z+$ 3 or 4 hard jets

MLM-like method

PS should not generate emissions much harder than those already included in the ME calculation

MLM suggested vetoing events when the PS changed the number or composition of cone jets

MLM *never* suggested adding samples of different topologies

Use of cone jets is clumsy, and can be biased

Alternative

1. Use `KTLCUS` or `PYCLUS` to define hardness of partons
2. Generate ME events with N QCD partons with a cutoff on hardness (say 10 GeV)
3. Feed into PYTHIA using LHA interface
4. Cluster showered partons (or particles) again
5. Veto if $(N + 1)$st hardness $>$ cutoff
6. Add up for $N = 0, 1, 2, \cdots$ [a]

[a] Treat highest N more loosely

Why does this work?

Each individual sample has a well-defined kinematic signature

- (a) $W+0$ k_T-jets$>$ cutoff + any number below cutoff
- (b) $W+1$ and only 1 k_T-jet$>$ cutoff + any number below
- (c) *etc.*

Vetoing an event with a hard emission is like reweighting by the Sudakov form factor on external lines

Internal lines are harder and would have Sudakov weights that are closer to 1

CKKW-like method: PseudoShowers

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In a real PS, N jets would emerge from N calculations of Sudakov branching probabilities

Alternatively, the N parton ME can be traced back to an N emission history

- Caveat: Mapping is approximate/arbitrary except in soft/collinear limit

Can step through this history and run pseudo-showers to determine if any hard emissions would occur[a]

Relatively easy to perform with PYTHIA

Advantage over the CKKW method in that it uses Sudakov and kinematics of the real generator (plus PYTHIA has a well-tuned UE description)

[a] CKKW showed that an internal rejection (different than a veto) should occur on the emissions, and this requires a hacked version of PYTHIA or move to 6.3

W+0 $\oplus \cdots \oplus$ W+4 hard partons

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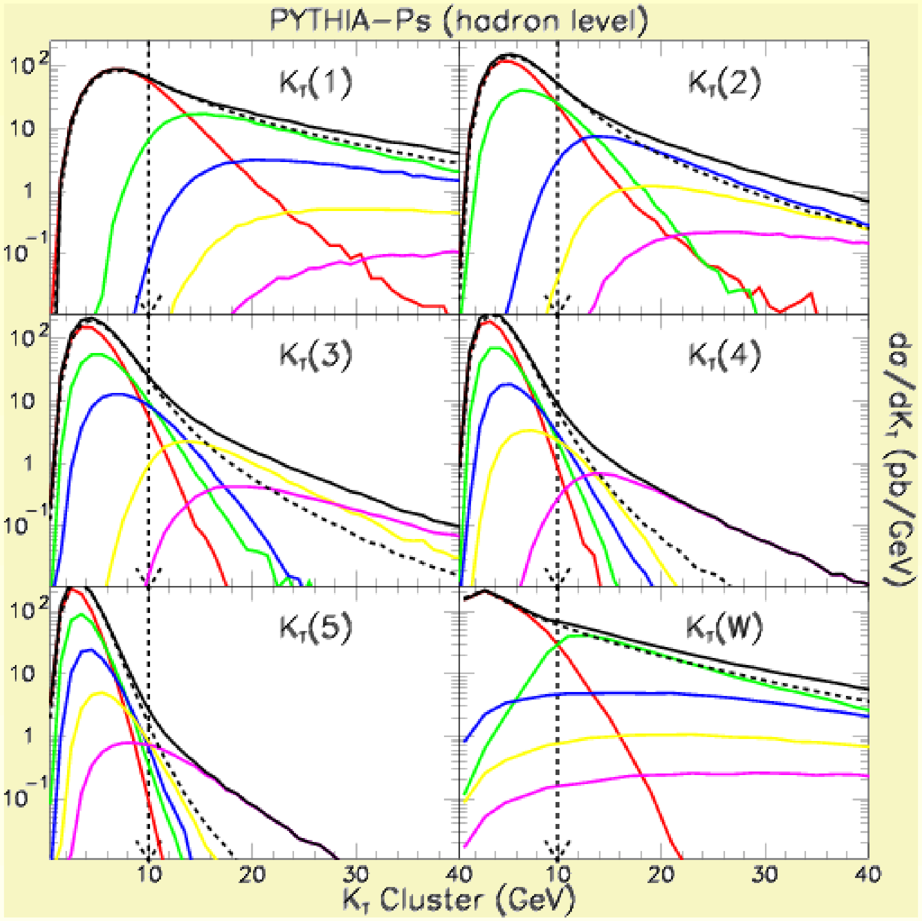

Dashed is `Pythia` with default (ME) correction

Solid is Pseudoshower result

Combines ME contributions (0, 1, 2, 3, 4 partons)